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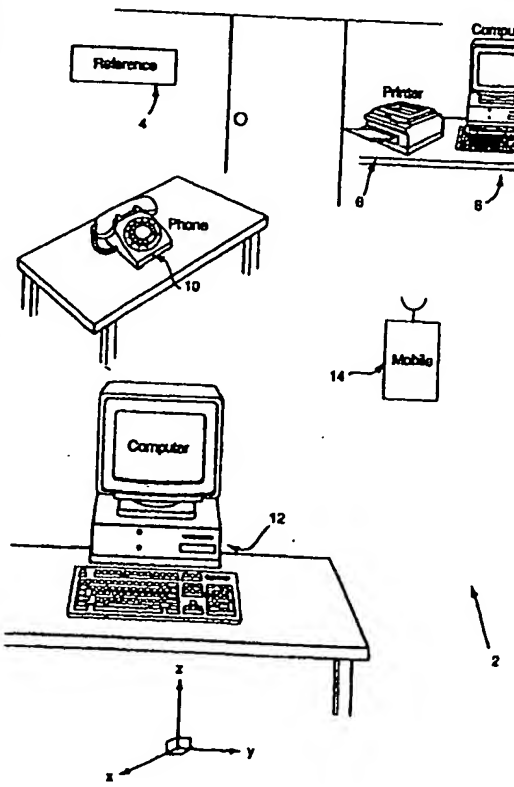

(57) Abstract: A first transceiver (4, 30) can position itself by forming an ad hoc network (20) of transceivers which assist the first transceiver in acquiring its position. A dedicated infrastructure such as GPS satellites is not required. The first transceiver (4, 30), once it has acquired its position, can be involved in a network (20) by another transceiver (32, 34, 36, 38, 40) to assist in the positioning of that transceiver. The acquisition of the position may involve factors such as the trustworthiness of the transceivers in the network and/or the positions of transceivers with which the first transceiver cannot directly communicate.

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Position Acquisition

The present invention relates to the use of wireless technology to estimate the position of a person or device. It particularly relates to a radio transceiver arranged to determine its location by receiving messages transmitted from a first plurality of proximal radio transceivers and also arranged to facilitate the determination of the location of a second proximal radio transceiver by transmitting a message or messages to that second proximal transceiver and to ad hoc networks formed by arrangements of such transceivers.

It is often desirable to be able to determine one's position or to determine the position of another person or device. The Global position system (GPS) allows the location of specialist receivers to be positioned on the surface of the earth. GPS uses a fixed network of satellite transmitters orbiting the earth to transmit to and thereby locate the receiver. Cellular positioning systems have also been proposed in which the existing network of fixed base station transceivers is used to locate a mobile phone. The unchanging position and identity of the fixed base stations and the distance of the mobile phone from the base stations is used to estimate the phones location. Both of these systems operate over large distances exceeding many kilometres.

A radio location system suitable for tracking objects over shorter distances is proposed in US 5,119,104. A fixed array of receivers is distributed over the area and a transmitter is attached to the object to be tracked. Time of arrival measurements of transmitted signals at the distributed receivers are used to locate the object.

It would be desirable to provide a system by which the location of persons or objects can be determined wirelessly but without having to invest in a dedicated fixed network of radio receivers.

It would be desirable to re-use existing wireless technology, which may be provided for a different purpose, to allow position determination.

According to a first aspect of the present invention there is provided a radio transceiver as claimed in claim 1, a method as claimed in claim 30 and an arrangement as claimed in claim 31. The arrangement may be time-variable in its distribution, number and/or identity of transceivers. Transceivers in an arrangement can form an adaptive and ad hoc network with proximal transceivers. The transceiver which forms the network can acquire its position from the other transceivers involved in the network and, after it has acquired its position, it can be included in a network by a proximal transceiver which is acquiring its position. This provides for the current proximal transceivers to be used for position determination instead of some fixed infrastructure.

According to a second aspect of the invention there is provided a radio transceiver as claimed in claim 32 and a method as claimed in claim 33. A transceiver can determine its position by taking into account not only the positions of the first order transceivers it can communicate with but also the positions of the second order transceivers it is unable to communicate with. This is particularly useful when the identities of and position information held by the first-order and second-order transceivers may change frequently.

According to a third aspect of the invention there is provided a radio transceiver as claimed in claim 34 and a method as claimed in claim 35. A transceiver determines its position by calculations involving the positions of first order transceivers, received from the transceivers, and a indication of the trustworthiness of the transmitting transceivers. For example, a reference transceiver will be trusted, whereas a very mobile transceiver will not. As opposed to the prior art where the positioning infrastructure is fixed and trustworthy, the transceivers which are used to acquire a position in embodiments of the invention change, perhaps frequently, and some will be

more reliable than others. This aspect of the invention addresses that problem.

According to a fourth aspect of the invention there is provided a receiver as claimed in claim 36 or a method as claimed in claim 48. This provides a neat and powerful methodology for calculating the probable position of a receiver.

For a better understanding of the present invention and to understand how the same may be brought into effect reference will now be made by way of example only to the accompanying drawings in which :

Figure 1 illustrates an office environment in which an ad hoc network of low power transceivers is formable;

Figure 2 illustrates a wireless network having a Master and a plurality of Slaves;

Figures 3a and 3b illustrate how the position of a Master is determined from information provided by the Slave according to separate embodiments;

Figure 4a, 4b and 4c illustrates how the network may be dynamically changed;

Figure 5 is a schematic illustration of a transceiver;

Figures 6a, 6b and 6c illustrate the operation of a Master in Position Acquisition Mode;

Figures 7a, 7b and 7c illustrate the operation of a Slave during position acquisition by the Master.

Figure 8 illustrates a distribution of transceivers T;

Figure 9 illustrates an exemplary probability density function representing the chances of successful transmission between transmitter and receiver as the distance between transmitter and receiver varies;

Figure 10 illustrates an exemplary probability density function representing the probable location of a transceiver on the x-axis; and

Figure 11 illustrates a transceiver

Figure 1 illustrates an office environment 2 in which an ad hoc network of low power transceivers is formable. There is shown in the figure a wall mounted reference transceiver 4 and a number of office appliances which are hosts to other transceivers. These appliances are a printer 6, a first computer 8, a desk telephone 10, a second computer 12 and a hand-portable communication device 14 such as a mobile phone. The reference transceiver 4 in this example is permanently positioned on the wall at a known location alternatively it could be mobile and have integrated position locating technology such as GPS. The transceivers in the printer 6, computers 8 and 12 and the desk phone 10 will move when the host is moved, which is likely to be infrequently. The low power transceiver in the portable device 14 is moved when the host is moved which is frequently. The reference transceiver 4 is optional and is not essential to the performance of the invention. Although an office environment 2 has been illustrated, this is only exemplary. In another network the portable device 14 may be a vehicle with another transceiver(s) embedded in other vehicle(s) and at the roadside.

Each of the low power transceivers can communicate with other transceivers that are within range and form an ad hoc network with those in-range transceivers. One of the transceivers acts as a Master of the network and the remaining transceivers are Slaves. The Master is at the centre of the network and normally communicates with a single Slave at any one time, although it is possible for it to broadcast to all the Slaves simultaneously. The network is a spoke network with the Master at the hub and a Slave at the end of each spoke which may be of different lengths.

The maximum extent of the network is determined by the distance at which the ability of the Master to communicate with a Slave transceiver is lost. The size of the network is determined by the number of Slave transceivers the Master can control. In the Bluetooth system (specification 1.0) this number is 7 Slave transceivers.

The ad hoc network formed by a Master may be used to determine the position of the Master transceiver. Referring to Figure 1, if the position of the portable device 14 was required, the transceiver hosted by the device would operate as a Master and create an ad-hoc network with those transceivers within range. In this example it is the reference transceiver 4, and those within the printer 6, computers 8 and 12 and the desk phone 10. The Master interrogates each Slave and from the responses received determines its position.

The Slaves are able to store an indication of their position. Typically each transceiver stores a record of its position in three dimensions.

In a first embodiment the position of the slave is transferred to the Master and the Master estimates the distance between a Slave of known position and itself. Typically this is done by receiving a signal transmitted from the Slave to the Master at a known power and by measuring the power of the signal received at the Master. The attenuation of the signal is calculated and the transmission distance estimated. If the transmission from Slave to Master is direct then the transmission distance corresponds to the distance between Slave and Master. It may alternatively be possible to use time of arrival (TOA) calculations to determine the separation distance of Slave and Master. The Master then uses the knowledge of the actual positions of the local transceivers and the knowledge of their respective distances from the Master, to estimate the actual position of the Master. The estimation may conveniently use fuzzy logic.

In a second embodiment the position of each Slave is transferred to the Master. The Master uses the position of each of the Slaves and the fact each slave is within a communication range to estimate its position. The estimation may conveniently use fuzzy logic. This method is less accurate than the method of the first embodiment but is less resource intensive and does not

require special circuitry to measure the power of received signals or their time of arrival.

The estimation may take into account for each of the Slaves the uncertainty in the position of a Slave. The value of this uncertainty is transferred from the Slave to the Master. The estimation may take into account for each of the Slaves the uncertainty in the distance calculated between Slave and Master. The value of this uncertainty is calculated in the Master. The estimation may take into account for each of the Slaves the likelihood that the Slave has been moved since it last recorded its position i.e. the likelihood that the record of position transferred from Slave to Master is incorrect. The transceivers may be rated according to their trustworthiness. Thus the reference transceiver 4 would be rated trustworthy, the transceivers in the printer, computers and desk phone would be rated neutral and the transceiver in the portable device would be rated as untrustworthy.

aggregate value.

The Master may then transmit its newly calculated position to the Slaves in the network. This may activate some of the Slaves to reacquire their position by acting as Master. That is, the network as a whole is adaptive.

Figure 2 is an illustration of a network 20. The network comprises Master transceiver 30 at the hub and Slave transceivers 32, 34, 36, 38 and 40 which lie within the perimeter 22 of the physical extent of the network. The transceivers 42, 44, 46 and 48 are not part of the network 20. The network 20 is determined by which of the transceivers 30, 32, 34, 36, 38, 40, 42, 44, 46 or 48 is acting as Master. It is preferable but not essential that each transceiver transmits with the same power and the physical extent of the network is determined by that power. It will be appreciated that if transceiver 36 were Master, the perimeter of the network would be designated by the dotted line 24 and that transceivers 38, 30, 34, 40, 42 and 44 would be Slaves to that ad hoc network.

Figure 3a illustrates how according to the first embodiment, for network 20 of Figure 1, the position of Master 30 may be estimated if the position of the transceivers 32, 34, 36, 38, 40 is known and the distance of those transceivers from the Master is known. For each Slave transceiver of known position, the Master should lie on the circle centred on the Slave transceiver's position which has a radius equal to the calculated distance between that Slave transceiver and the Master transceiver. The greater the number of Slave transceivers of known position used the greater the potential accuracy of locating the Master transceiver.

Fig 3b illustrates how according to the second embodiment, for network 20 of Figure 1, the position of Master 30 may be estimated if the position of the transceivers 32, 34, 36, 38, 40 is known and the maximum distance of those transceivers from the Master is known. In the illustrated example each of the transceivers transmits at the same power and so each has the same range. This simplifies the example but is not essential. What is important is for the Master to know the maximum range of each of the Slaves. For each Slave transceiver of known position, the Master should lie with the circle centred on the Slave transceiver's position which has a radius equal to that transceiver's transmission range. The greater the number of Slave transceivers of known position used the greater the potential accuracy of locating the Master transceiver.

Fig 4a illustrates the network 20 at a later time, when the transceiver 30 has started position acquisition and is therefore acting as Master. However, a new transceiver 50 has come within the perimeter 22 and is a Slave transceiver in the network 20.

Fig 4b illustrates the network 20 at a later time, when the transceiver 30 has started position acquisition and is therefore acting as Master. However, transceivers 32, 36 and 44 have been moved. The transceivers 32 and 36 are no longer within the perimeter 22 and do not form part of the network 20.

Fig 4c illustrates the network 20 at a later time, when transceiver 30 has started position acquisition and is therefore acting as Master. The Slave transceivers 32, 34, 36, 38 and 40 present in network 20 illustrated in Fig 4a are still present but they have been moved but remain within the perimeter 22.

Network 20 is dynamic in that the constituent transceivers are changeable. The network is ad hoc in that any transceiver may act as Master and create a network, the other transceivers within range functioning as Slaves.

Figure 5 illustrates a low power radio frequency transceiver 100. The transceiver preferably operates in accordance with the Bluetooth protocol. An example of an exemplary LPRF transceiver is described in UK Patent Application No 9820859-8 the contents of which are hereby included by reference.

According to the Bluetooth protocol, a transceiver may variably act as a Master controlling a network or as a Slave within a network. The Master and Slave transceivers communicate using data packets. The transceivers within a network operate in a time division duplexed fashion and transmission and reception at one transceiver does not occur simultaneously.

According to embodiments of the invention, the transceiver 100 comprises an antenna 102, transmitter circuitry 104, reception circuitry 106, a processor 120, a memory 140 for an ad hoc network database, a memory 122 storing a code for uniquely identifying the transceiver to other transceivers, a memory 124 for storing the current position of the transceiver, a memory 126 for storing a position error which indicates the accuracy of the value stored in memory 124, a memory 128 for storing a value representing the power at which the transceiver transmits, and a memory 130 which stores a value indicating the trustworthiness of the content of memory 124.

The unique ID may be read by the processor 120 and is used by the transceiver when transmitting to correctly identify the source of transmissions.

The position value stored in memory 124 is typically a three dimensional co-ordinate (x, y, z), where x, y and z are suitable, possibly different, units of measurement indicating a position from a uniquely defined origin. The x, y and z axes are illustrated in Figure 1. In one possibility the values x and y may be measured in metres and the value z may indicate the correct floor of the building. The position error may have three values X, Y and Z, indicating the potential error in x, y and z respectively or be a single value. The processor 120 is able to write to and read from memories 124 and 126.

Preferably all the transceivers operate at the same power level. The processor 120 reads the value from memory 128 which represents the power of the transmitter circuitry 104. The value in memory 128, may if necessary be adjusted via a signal 132 .

The value stored in memory 130 indicates the likelihood of the transceiver having been moved since its position was last determined and hence the likelihood that the values in memory 124 and 126 are incorrect. A fixed or permanent reference transceiver has a value [11] (trustworthy), a transceiver in a movable or semi-permanent host has a value [10] (neutral) and a transceiver in a portable host has a value [01] (untrustworthy). A motion detector within the host may also or alternatively be used to reset, using signal 134, the value in memory 130 to [00] (incorrect). The processor 120 is able to read memory 130. The memory 140, stores a database containing entries for each Slave transceiver of the ad hoc network for which the transceiver was last Master or is currently Master. The database has a row for each of the Slave transceivers. In the first and second embodiments each row preferably has 5 fields: Slave ID, Slave Position, Slave position error, Slave rating, and a final field. In the first embodiment this field is a measure of the distance

between Master and Slave. It may be the received power level of Slave or the conversion of this value into a distance or a distance probability e.g. d<2m; 2m< d < 4m). In the second embodiment the last field is a measure of the maximum transmission range of each Slave and may consequently not be used if all transceivers transmit with a predetermined power and therefore have a predetermined range.

For a particular row, the values in the fields record the situation when the network was last active. The slave ID is the unique ID stored in memory 122 of a particular Slave and was transferred to the Master via the network. The Slave Position and Slave Position Error are the values which were stored in the memory 124 and 126 respectively of that particular Slave when the network was last active and were transferred to the Master over the network. The Slave rating is the value which was stored in the memory 130 of that particular Slave when the network was last active and was transferred to the Master over the network.

As an example the content of the database 140 for the transceiver 30 illustrated in Figure 2 may for a transceiver according to the first embodiment be something like:

Slave ID	Slave Position		Slave Position Error		Slave Rating	Distance (m)
	x	y	X	Y		
32	42	43	1	1	[11] trustworthy	4
34					[10] neutral	
36	68	8	1	2	[10] neural	5
38						
40	88	19			[10] neutral	6

The third dimension z, Z has not been used. In this example, transceiver 38 is a Bluetooth transceiver and can therefore form part of the network 20, but it does not have the necessary functionality to perform or assist in position acquisition. It has therefore been identified in field 1, but the remaining fields are empty. Transceiver 34 is a Bluetooth transceiver with the correct functionality to perform and assist in position acquisition, but it has not yet acquired its own position. It has therefore been identified in fields 1 and 4, but the fields relating to location are empty.

The database 140 is completely rebuilt each time the transceiver 100 forms a network.

Although described as different memories, the memories 122, 124, 136, 128, 130 and 140 may be implemented as different parts in one or more memories.

The processor 120 provides data 108 to transmitter circuitry 104 for transmission via antenna 102. Antenna 102 is also connected to receiver circuitry 106 which supplies received data 110 to the processor 120.

The receiver circuitry 106 may optionally have additional circuitry (not shown) for measuring the power of a signal received by antenna 102 and it supplies an indication of the received signal strength to the processor via signal 112.

First Embodiment

The process of Position Acquisition in accordance with the first embodiment will now be explained in more detail with reference to Figures 6a, 6b and 6c which describe events occurring in the network Master and Figures 7a, 7b and 7c which describe events occurring in each of the network Slaves.

A transceiver forms an ad hoc network by functioning as a Master. While functioning as a Master the transceiver can determine its position by entering the Position Acquisition Mode 200. The Master transceiver polls local transceivers 202 to form an ad-hoc network. The Master transceiver determines 204 the number M of Slave transceivers in the network. The Master transceiver then creates the database 140 for the network by performing a series 206 of steps for each Slave transceiver. The Master transceiver sends 208 a Request signal addressed to a first Slave transceiver. The Master then awaits 210 a response from the first Slave transceiver. The absence of a response indicates that the first Slave transceiver does not have the appropriate functionality to assist in position acquisition. A response form a first Slave transceiver which has previously acquired its own position includes the fields for the database: Slave ID, Slave Position, Slave Position Error and Slave Rating . This information is transferred from the first Slave transceiver to the Master in the payload of a packet and written 216 along with the calculated value for the distance between Master and Slave, to the first row of the database 140.

A response form a first Slave transceiver which has not previously acquired its own position includes the fields for the database: Slave ID, Slave Rating . This information is transferred from the first Slave transceiver to the Master in the payload of a packet and written to the first row of the database 140.

If the Slave transceiver has previously acquired its own position, then the steps 212 and 214 are carried out before the database is written to, to determine the fifth field of the database, Distance. At step 212 the power of the incoming signal strength from the first Slave transceiver is sampled and this is used in step 214 to estimate the distance between the Master and first Slave. The power at which the first Slave is transmitting is either a standard value or the value is transferred from Slave to Master. A comparison of the received power of a signal transmitted from the first Slave and the power of

the transmitted signal allows the amount of attenuation to be calculated and the distance between Slave and Master to be estimated.

A row of the database is completed for each of the Slaves by cycling through loop 206. When, the database is complete the loop 206 is exited at A.

Referring to Figure 6b, the Master then calculates 220 the position of the Master from the information recorded in fields 2, 3 and 5 of the database 140 (Slave Position, Slave Position Error and Distance) and estimates the error in the calculated Master position.

If the error is sufficiently small 222, then the position values are stored to memory 124 and the error values are stored to memory 126 with the old values (if any) temporarily stored in the processor 120.

If the error is greater than a predetermined value E1, then a weighted calculation of the Master position is made on the basis of the information stored in fields 2, 3, 4 and 5 of the database 140 (Slave Position, Slave Position Error, Slave Rating and Distance). In this weighted calculation, the values for trustworthy Slaves (rating =[11]) are double entered and the values for untrustworthy Slaves (rating =[01]) or incorrect Slaves (rating =[00]) are ignored. The weighted calculation produces a new position for the Master and a new error value.

If the error is sufficiently small 226, then the position values are stored to memory 124 and the error values are stored to memory 126 with the old values (if any) temporarily stored in the processor 120.

If the error is greater than a predetermined value E2, then a second-order position calculation is performed. The first-order network is that network formed by the current Master which is acquiring its position and the other transceivers in the network are first order Slaves. A second order network is

one formed when a first order Slave acts as a second-order Master and creates a network with second-order Slaves. The previously described position calculations were first-order in that they only used position information about first-order Slave transceivers to the first-order Master's network. A second order calculation in addition to using position information about first-order Slave transceivers to the Master's network, uses information about second-order Slave transceivers. Information about the second-order Slaves is stored in each of the databases 140 of the first-order Slaves. This information describes the last ad-hoc network a now first-order Slave formed when it was previously a second-order Master. The first-order Master transceiver requests the transfer of each of its Slaves' databases 140.

From the second-order databases, the Master determines the areas the Master cannot be located in because the Master does not have identified second-order Slaves as first-order Slaves. The Master then uses the information in its database concerning the position of the first order Slaves to determine the area in which the Master may be located. The Master uses the information about second-order Slaves transferred from the databases of the first-order Slaves to identify second-order Slaves which are outside communication range with the Master and are not therefore first order Slaves. The Master excludes portions of that newly determined area in which the Master cannot be located as it is out of range of the identified second order Slaves. The result is converted into position values with associated error values. The position values are stored to memory 124 and the error values are stored to memory 126 with the old values (if any) temporarily stored in the processor 120.

The difference between the old and new values of position are compared 232 and if they exceed a threshold value an Updating routine 240 is started at B, in which the new values are communicated to the Master's Slaves allowing them to update their databases 140, and if necessary re-acquire their position

in the light of that new information. If the difference in position does not exceed a threshold, then the difference in error is calculated. If this exceeds a threshold the Updating routine 240 is entered at B. If the difference does not exceed a threshold E2, then the Position Acquisition Mode is exited 236 and the program returns 238.

The updating routine 240 is illustrated in Figure 6c. The Master sends an Update packet to each one of the Slave's in its network. The packet has a payload containing ID (read from the Master's memory 122), Position (read from the Master's memory 124), Position Error (read from the Master's memory 126), Transmit Power (read from the Master's memory 128) and Rating (read from the Master's memory 130).

Figure 7a illustrates the process of Request – Response which occurs in a Slave. If the transceiver is in Slave Mode 302 and it receives a position acquisition request 304 from a Master transceiver, the Slave responds 306 by reading from its memories 122, 124, 126, 128 and 130 and sending a packet to the Master. The packet has a payload containing Slave ID (read from the Slave's memory 122), Slave Position (read from the Slave's memory 124), Slave Position Error (read from the Slave's memory 126), Transmit Power (read from the Slave's memory 128) and Slave Rating (read from the Slave's memory 130).

Figure 7b illustrates how a Slave may respond to receiving an Update packet from the Master (see Figure 6c). When the transceiver is in the Slave Mode 310 and it receives an Update packet from the Master 312, it temporarily stores the information content in its processor 120. The processor 120 then examines the database 140 of the Slave, to determine if there is already a record there for a transceiver with the same ID. If there is no such record, the Slave enters the position acquisition mode 320 which has been described in relation to Figures 6a, 6b and 6c. If a record already exists, then the distance between the old position for the transceiver and the new position are

compared. If they differ by more than a threshold value then the position acquisition mode in entered 320. If they differ by less than the threshold, then the difference in the error values for the new record compared to the old record are compared. If the difference exceeds a threshold value then the position acquisition mode is entered, if not the Slave returns to its idle state.

Figure 7c illustrates how a Slave transceiver responds to a request for second order position acquisition. The Slave sends the contents of its database 140 to the Master.

Second Embodiment

The procedure of position acquisition by the Master previously described in relation to Figures 6a, 6b and 6c according to the first embodiment, is similar for the second embodiment. The differences are:

after step 210 and before step 216 there is a single step in which the Master determines the maximum communication range for the Nth Slave which is subsequently stored in the 5th field of the database in step 216;

the step of calculating the new position of the master with error 220 is as previously described in relation to Figure 3b using the information recorded in fields 2, 3 and 5 of the database 140 (Slave Position, Slave Position Error and Maximum range).

The process of Request – Response which occurs in a Slave according to the second embodiment is the same as described in relation to Figures 7a, 7b and 7c. If the Slaves transmit at a constant power (and therefore have constant range), then the Slave will transmit a packet to the Master.

The packet has a payload containing Slave ID (read from the Slave's memory 122), Slave Position (read from the Slave's memory 124), Slave Position Error (read from the Slave's memory 126), and Slave Rating (read from the Slave's memory 130).

If the Slaves transmit at different power levels, then each payload will additionally need to contain Transmit Power (read from the Slave's memory 128) . This indication of its transmitting power level is also an indication of its transmitting range.

From the foregoing description it will be appreciated that a transceiver which needs to acquire its position can do so by communicating with nearby transceivers. A transceiver may enter the position acquiring mode in response to an interrupt. This interrupt may be manually generated by a user through a user interface or from a clock within the transceiver. For example, such interrupts may be generated regularly by a clock every 30 minutes. The duration between interrupts may be programmable. An interrupt may optionally be produced when a transceiver is polled by a newly local transceiver or when the transceiver polls a newly local transceiver. A transceiver also enters the position acquisition mode in step 320 of Figure 7b.

The network may be set up and/or calibrated using a portable transceiver which also contains other positioning technology. This positioning technology may be a GPS circuit which gives the location of the device in global co-ordinates. Less advantageously the positioning technology may be mobile radio telephone circuitry for use in a cellular network of fixed radio base stations and adapted to use an estimation of its distance from the local fixed base stations to estimate its position. Such a device may be rated as a reference device and will set up local transceivers by providing them with information about its position. The reference device enters the position acquisition mode as illustrated in Figure 6a. At step 220 it uses its positioning technology to calculate the new position and then jumps to step 230. Likewise, when the reference device responds to the master at step 306 it uses its positioning technology to calculate its position and uses this position in its response to the Master. The reference device need not remain within a particular network zone but can migrate through many network zones

calibrating each. It is not essential for an ad hoc network to have a reference transceiver.

An alternative Second Embodiment

In the alternative second embodiment the position of each Slave is transferred to the Master as a probability function. The Master estimates or derives a probability function representing the likelihood of successful transmission from the Slaves to the Master. The Master uses the probable position of each of the Slaves and the probability function representing the likelihood of successful transmission to estimate its position.

The described database needs some modification to accommodate this alternative embodiment. The Slave Position and Slave Position error may be the mean and standard deviation if the probable position can be represented as a normal distribution, otherwise they should be replaced by the probability function representing the Slave's position. The Final field will be used to record the probability function representing the likelihood of successful transmission, if it varies from Slave to Slave.

Figure 9 illustrates a transceiver T*i* which is capable of forming an ad hoc network 2 via radio communications with the transceivers T*j*. The network may be formed by T*i* acting as a Master with the transceivers T*j* functioning as Slaves. Preferably the transceivers are Bluetooth transceivers and the network is a piconet. When the transceiver T*i* acquires its position it forms a network with neighbouring transceivers T*j* which have already acquired their positions. The communication range of transceiver T*i* is illustrated by the circle 4. There are a number of transceivers T*j* which are outside the range 4 and cannot participate in the network 2.

The transceiver T*i*, once it has acquired its position it can participate as a Slave in a different network formed by another transceiver to acquire its position. Each of the transceivers T are the same. Each acts as a Master to form a network with Slave transceivers to acquire a position and then it can participate as a Slave in a different network formed by another transceiver to acquire its position. The transceivers T are not infrastructure. They are preferably integrated into host devices such as mobile phones, desk telephones, computers etc. The transceivers which are available to participate in a network may therefore vary as transceivers move into and out of range of the Master transceiver.

Referring to Figure 9, the transceiver T*i* is attempting to determine its position. It forms a network with N transceivers T*j* where *j* = 1, 2, 3...N.

The probability that a transceiver T*j* can transmit successfully to the transceiver T*i* when separated by distance *y* is given by $prob_{TransSuccessful.ji}[y]$ .The probability density function representing the probability a transceiver j can transmit successfully to the Transceiver T*i* is given by $pdf_{TransSuccessful.ji}[y]$

where

$$pdf_{TransSuccessful.ji}[y] = \frac{prob_{TransSuccessful.ji}[y]}{\int_{-\infty}^{\infty} prob_{TransSuccessful.ji}[y]dy}$$

If all transmitters *Tj* are equal, $prob_{TransSuccessful.ji}[y]$, may be replaced by $prob_{TransSuccessful}[y]$ which represents the probability that any one of the transceivers T*j* can transmit successfully to the transceiver T*i* when separated by distance *y*. The probability density function representing the probability a transceiver j can transmit successfully to any one of the Transceiver T*i* is given by $pdf_{TransSuccessful.ji}[y]$ where

$$pdfTransSuccessful[y] = \frac{probTransSuccessful[y]}{\int_{-\infty}^{\infty} probTransSuccessful[y]dy}$$

Figure 10 illustrates an exemplary probability density function representing the chances of successful transmission between a transmitter and receiver T*i as* the distance between transmitter and receiver varies. The probability density function may be based on measurements for example by sounding the communication channel between transmitter and receiver . The probability density function may be an approximation, chosen to ease subsequent calculations. The illustrated probability density function is an approximation which eases subsequent calculations. It assumes that within a certain range of the transmitter the chances of reception are good and constant, but at a certain threshold distance from the transmitter the chances of reception decrease proportionally with the distance travelled from the threshold.

The transceivers T are preferably positioned in three dimensions with respect to three orthogonal linear axes. Although this is not essential, it provides advantages because the positioning of a transceiver with respect to one of the axes is independent of the positioning with respect to the other two axes. The transceiver is therefore positioned in three dimensions by positioning it separately with respect to each axes. In the following description the positioning of a transceiver T*i* with respect to one axes is described. Analogous procedures are carried out for the remaining axes.

Each transceiver is positioned with respect to the linear axis using a probability density function. The transceiver T*j* is positioned with respect to the linear axis by $pdf_j[z]$ where the argument indicates a position of the transceiver T*j* from an origin common to the transceivers Tj . The function pdf_j [*z*] varies as the argument varies having a maximal value at where the most

likely acquired position for transceiver T*j* is. The transceiver T*i* will acquire its position by calculating a probability density function $pdf_i[z]$ for itself.

Figure 11 illustrates an exemplary probability density function $pdf_i[z]$ representing the probable location of a transceiver on the x-axis, where z represents a distance along the x-axis.

When the transceiver T*i* is acquiring its position, it receives $pdf_j[z]$ from each of the N transceiver Tj where j= 1, 2, 3 ...N. That is it receives $pdf_1[z]$ from T*1*, $pdf_2[z]$ from T*2*, $pdf_3[z]$ from T*3*, etc.

If all transmitters *Tj are* equal, there is no necessity for each of the transmitters j to send $prob_{TransSuccessful\ j}[y]$. The values of $prob_{TransSuccessful}[y]$ may be stored in T*i*. However, if the transmitters T*j* have different transmission characteristics such as different transmission power levels then it may be appropriate for each of the transceivers T*j* to transmit $prob_{TransSuccessful\ j}[y]$ to the transceiver T*i*.

On the basis of this information the transceiver T*i* can calculate its position according to a first order calculation. This first order calculation takes into account, the transceivers T*j* with which the transceiver Ti can directly communicate. The calculation determines where the transceiver T*i* could be because it can communicate with the transceivers T*j*.

The transceiver T*i* can calculate its position density function $pdf_i[z]$, which takes into account all the transceivers T*j*, by combining the intermediate probability density functions $pdf_j[y]$
calculated because the particular Transceiver T*j* can communicate with T*i*, for all *j*.

The intermediate probability density functions $pdf_{ij}[y]$ calculated because the particular Transceiver T*j* can communicate with T*i* is given by:

$$pdfij[y] = \frac{\left(\int_{-\infty}^{\infty} pdfj[z]\, probTransSuccessful.ji[y-z]dz \right)}{\int_{-\infty}^{\infty} \left(\int_{-\infty}^{\infty} pdfj[z]\, probTransSuccessful.ji[y-z]dz \right) dy}$$

This can be converted using mathematics to:

$$pdfij[y] = \int_{-\infty}^{\infty} pdfj[z]\, pdfTransSuccessful.ji[y-z]dz$$

The probability density function representing the position of the receiver T*i* is therefore given by the convolution of the probability density function representing the position of the transmitter T*j* with the probability density function representing the likelihood of successful transmission from the transmitter to receiver.

The transceiver T*i* can calculate its position density function $pdf_i[z]$, which takes into account all the transceivers T*j*, by combining the intermediate probability density functions $pdf_{ij}[y]$ calculated because the particular Transceiver T*j* can communicate with T*i* as follows:

$$pdf_i[y] = \frac{\prod_{j=1}^{N} \alpha_j pdf_{ij}[y]}{\sum_{y'} \left(\prod_{j=1}^{N} \alpha_j pdf_{ij}[y'] \right)} \qquad where \sum_{j=1}^{N} \alpha_j = 1$$

where α_j is a parameter which represents how trustworthy the Transceiver T*j* is. For example, if the transceiver T*j* is a reference station it will have a high value, whereas if the transceiver T*j* is very mobile it will have a low value. It should be appreciated that the values α_j may be transmitted by transceiver T*j* to transceiver T*i* (although renormalisation will be required such that $\Sigma\alpha_j = 1$), or the values of α_j may be calculated by T*i* on the basis of information received from the transceivers T*j* such as other indications of their trustworthiness.

The use of trustworthiness in the calculation can be disabled by setting $\alpha_j = 1$ for all j.

The above calculation of $pdf_i[z]$ effectively determines the renormalised overlap of the probability density functions $pdf_{ij}[z]$ (taking into account their trustworthiness if appropriate) for all j. A problem, however, arises if the probability density functions $pdf_{ij}[z]$ do not overlap.

A preferred method of combining the intermediate probability density functions $pdf_{ij}[y]$ takes into account that the intermediate probability density functions $pdf_{ij}[y]$ may not all overlap. The method combines the intermediate probability density functions in a pair-wise fashion. If the pair of probability density functions which are to be combined do overlap the method calculates the renormalised overlap of the two intermediate probability density functions. However, if the pair of probability density functions which are to be combined

do not overlap, the method calculates a weighted sum of the two probability density functions.

One manner of implementing the preferred method will now be described. In this preferred method the transceiver Ti, before it has acquired its new position, may have no current position or may have a position which has expired. If the current position has expired the variable $pdf_{i\,(old)}[y]$ is set equal to the current expired value of $pdf_i[y]$. If there is no current position the variable $pdf_{i\,(old)}[y]$ is set equal to 0. A temporary variable $pdf_{i\,Temp.j}[y]$ is assigned for use in the calculation. It is initially set for j=0, equal to $pdf_{i\,(old)}[y]$. The temporary variable $pdf_{i\,Temp.j-1}[y]$, is combined in a pair-wise fashion with $pdf_{i\,.j}[y]$, starting with the pair-wise combination of variable $pdf_{i\,Temp.0}[y]$ with $pdf_{i\,.1}[y]$ to produce $pdf_{i\,Temp.1}[y]$, then the pair-wise combination of $pdf_{i\,Temp.1}[y]$ with $pdf_{i\,.2}[y]$ to produce $pdf_{i\,Temp.2}[y]$, etc., ending with the pair-wise combination of $pdf_{i\,Temp.N-1}[y]$ with $pdf_{i\,.N}[y]$ to produce $pdf_{i\,Temp.2}[y]$ which is the position of Ti ($pdf_i[y]$) taking into account only the first order transceivers T*j*, for j=1, 2, 3...N.

The method can be coded as follows:

Start Code:

Initial condition: $pdf_{i\,Temp.0}[y] = pdf_{i\,(old)}[y]$

Body of the loop started with j=1 and exited at j=N

{

(Test for overlap between $pdf_{i\,Temp.j-1}[y]$ & $pdf_{ij}[y]$)

$$If \sum_{y'} pdfiTempj-1[y']pdfij[y'] \neq 0 \quad then$$

(If there is overlap, calculate the renormalised overlap)

$$pdfiTempj = \frac{pdfiTempj-1[y]\alpha jpdfij[y]}{\sum_{y'}(pdfiTempj-1[y']pdfij[y'])}$$

else

(If there is no overlap, calculate a weighted sum)

$$pdfiTempj[y] = pdfiTempj-1[y] + \alpha jpdfij[y]$$

}End of loop

Final result: $pdf_i[y] = pdf_{i\,Temp.N}[y]$

End Code

Thus far the value of $pdf_i[y]$ representing the position of the transceiver *Ti*, takes into account only the transceivers T*j* {*j*=1,2,..N}, which can communicate directly with the transceiver T*i*. Each of the transceivers T*j* may be able to directly communicate directly with transceivers with which the transceiver T*i* is unable to directly communicate. Such transceivers are second order transceivers as the transceiver *Ti* which is acquiring its position cannot communicate to them directly but can receive information about them from the transceivers it can communicate with. Information about the second order transceivers can be used to additionally refine $pdf_i[y]$ so that it takes account not only of where the transceiver T*i* could be because it can directly communicate with transceivers T*j* but also where it could not be because it cannot communicate with the second order transceivers.

Let each of the second order transceivers be designated by T*k*, where $k \neq j$ and $k \neq i$, k= 1, 2..M.

In the above coding, the loop is directly followed and the "Final result" is directly preceded by the coding:

Body of the loop started with k=1 and exited at k=M

{

$$prob_{noreception.ki}[y] = \sum_{z} pdf_k[z](1 - prob_{TransSuccessful.ki}[y - z])$$

$$pdf_{iTempk} = \frac{pdf_{iTempN}[y]\, prob_{noreception.ki}[y]}{\sum_{y'}(pdf_{iTempN}[y]\, prob_{noreception.ki}[y])}$$

$pdf_{iTemp.N}[y] = pdf_{iTemp.k}[y]$

}end of loop

It will be necessary for the transceiver to receive the values of $pdf_k[y]$ via the first order transceivers which are in communication with the second order transceivers.

Likewise $prob_{TransSuccessful.ki}[y]$ should also be transmitted to T*i* via the first order transceivers T*j*. However, if all the second order transceivers are the same then $prob_{TransSuccessful.ki}[y]$ will be a constant and can be stored. According to a one embodiment, the approximate value $prob_{TransSuccessful}[y]$ which was used in the first order calculations is also used in the second order calculations.

The probability density function representing a position of a transceiver will normally have a normal distribution as illustrated in Figure 3. Advantages can be achieved by assuming such pdfs have a normal distribution. The completed information required to define a normal distribution is the mean and the standard deviation. Consequently the probability density function representing the position of a transceiver can be transmitted using only two parameters- the mean and standard deviation.

Figure 12 illustrates a transceiver suitable for carrying out the invention. It comprises transmitter circuitry, receiver circuitry, a processor and a memory. The memory stores the above described algorithm. The processor executes the algorithm. The parameters used as input to the algorithm are stored in the memory and the result of the algorithm, the position of the transceiver, is also stored in the memory. When the transceiver operates as a receiver, to acquire its position, it receives the parameters it requires for the algorithm from the transceivers it is in communication with and stores them in the memory. When the transceiver operates as a transmitter, it is operable to transmit its stored position to the receiving transceiver using its transmission circuitry. The algorithm may be transported for transfer to a transceiver using a carrier such as a CD-ROM or floppy disc.

The transceivers hereinbefore described may be conveniently integrated into mobile phones and the mobile phone may be used to communicate the phones acquired position over the radio interface for use within the network such as the provision of value added services or elsewhere.

The transceiver when acting as a Master may request some user input to assist it in the acquiring of a position such as the selection betweeh two or more ambiguous positions.

Although the present invention has been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications and variations to the examples given can be made without departing from the scope of the invention as claimed.

Claims

1. A radio transceiver for use in a variable arrangement comprising a plurality of radio transceivers, operable:

to form a wireless network with proximal ones of said plurality of transceivers and to control that network;

to calculate, when controlling a network, its position by processing position-related messages received from the proximal transceivers in the network;

to be included in a network controlled by a proximal one of said plurality of radio transceivers; and

to transmit, when included in a network controlled by said proximal controlling radio transceiver, to the proximal controlling radio transceiver at least one position-related message.

2. A radio transceiver as claimed in claim 1, wherein each position-related message has a predetermined format and a content dependent upon the position of the radio transceiver from which it is transmitted, comprising:

a memory;

receiver circuitry operable when the radio transceiver controls the network to receive a position related message from each of the proximal transceivers included in the network;

processing means operable to determine, from the received position-related messages, location data identifying the position of the radio transceiver and store the determined location data in the memory; and

transmitter circuitry operable, when the radio transceiver is included in a network, to transmit to the proximal controlling radio transceiver at least one position-related message having said predetermined format and a content dependent upon the radio transceiver's determined location data stored in the memory.

3. A radio transceiver as claimed in claim 1 or 2 wherein each position-related message comprises an indication of position of the radio transceiver from which it is transmitted.

4. A radio transceiver as claimed in claim 3 wherein each position-related message additionally comprises an indication of error in position.

5. A radio transceiver as claimed in any preceding claim arranged to store an indication of trustworthiness related to the probable accuracy of the position-related messages it transmits when included in a network.

6. A radio transceiver as claimed in claim 5 wherein said indication of trustworthiness identifies the radio transceiver as portable.

7. A radio transceiver as claimed in claim 5 wherein said indication of trustworthiness identifies the radio transceiver as a reference type, having a reliable position.

8. A radio transceiver as claimed in any one of claims 5 to 7, wherein the position-related message transmitted by the transceiver includes said indication of trustworthiness.

9. A radio transceiver as claimed in any preceding claim arranged to store identification data uniquely identifying the radio transceiver, wherein position-related messages transmitted by the transceiver include said identification data.

10. A radio transceiver as claimed in any preceding claim wherein the position-related message includes an indication of the power at which the position-related message is transmitted or an indication of the range of transmission for the transceiver.

11. A radio transceiver as claimed in any preceding claim wherein the calculation of position from the received position-related messages comprises a first–order calculation based upon the positions of the proximal radio transceivers, each being radio transceivers which can directly communicate by transmission and reception with the radio transceiver.

12. A radio transceiver as claimed in any preceding claim wherein said calculation of position from the received position-related messages comprises a second–order calculation including calculations based upon the positions of non-proximal ones of said plurality of radio transceivers each of which can directly communicate by transmission and reception with at least one of the proximal transceivers but cannot directly communicate with the radio transceiver.

13. A radio transceiver as claimed in any preceding claim wherein said calculation of position from the received position-related messages includes calculations based upon the positions and the maximum communication range of each of the first plurality of proximal transceivers.

14. A radio transceiver as claimed in any one of claims 1 to 12 wherein said calculation of position from the received position-related messages includes calculations based upon the positions and estimated distance to the radio transceiver for each one of the first plurality of proximal transceivers.

15. A radio transceiver as claimed in claim 14 further comprising power detection circuitry for detecting the power of a received signal and estimation means for estimating from the detected power of a received signal the distance to the one of the first plurality of proximal transceivers which transmitted the signal.

16. A radio transceiver as claimed in any one of claims 1 to 12 wherein said calculation of position from the received position-related messages includes

the convolution of the probability density functions, representing the position of the proximal transceivers, included in received position-related messages with probability density functions representing the likelihood that a transmission from the proximal transmitting transceivers will be successfully received at the radio transceiver.

17. A radio transceiver as claimed in any preceding claim wherein said calculation of position from the received position-related messages comprises calculations dependent upon the trustworthiness of at least one of the proximal transceivers.

18. A radio transceiver as claimed in any preceding claim wherein said calculation of position from the received position-related messages comprises weighted calculations dependent upon the trustworthiness of the proximal transceivers.

19. A radio transceiver as claimed in any preceding claim arranged to transmit a request to each of the proximal transceivers

20. A radio transceiver as claimed in any preceding claim arranged, in response to a received request, to transmit said position-related message to the transceiver which made the request.

21. A radio transceiver as claimed in any preceding claim further comprising control means for controlling the transceiver to act as a Master and form a wireless network with said proximal transceivers as Slaves.

22. A radio transceiver as claimed in any preceding claim further comprising control means for controlling the transceiver to act as a Slave included in a wireless network .

23. A radio transceiver as claimed in any preceding claim operating in accordance with the Bluetooth wireless protocol.

24. A radio transceiver as claimed in any preceding claim comprising control means for causing the transceiver to enter a position acquisition mode in which:
the transceiver transmits requests to each of the first plurality of proximal transceivers;
the transceiver receives in response a position-related message from each of the first plurality of proximal transceivers; and
the transceiver processes the position-related messages to estimate its location.

25. A radio transceiver as claimed in any preceding claim arranged to transmit to each of the first plurality of transceivers, after the calculation of its position, to inform them of its newly calculated position.

26. A radio transceiver as claimed in claim 25 wherein said transmission to each of the first plurality of transceivers to inform them of the newly calculated position is conditional upon the newly calculated position differing substantially from a previously calculated position.

27. A chipset for a radio transceiver as claimed in any preceding claim wherein the chipset provides the processing means operable to determine location data identifying the location of the radio, and control means for controlling the transmitter circuitry to transmit a message or messages dependent upon said location data.

28. A radio transceiver substantially as hereinbefore described with reference to the accompanying Figures and/or as shown in the Figures.

29. An arrangement of transceivers substantially as hereinbefore described with reference to the accompanying Figures and/or as shown in the Figures.

30. A method by which a first radio transceiver that has not acquired its position can acquire its position by the formation of an ad hoc radio communications network with a plurality of proximal radio transceivers which have already acquired their position and which assist the radio transceiver in its position acquisition, wherein the first radio receiver, after having acquired its position, is thereby able to assist, as part of an ad hoc radio communications network, a second radio transceiver that has not acquired its position to acquire its position ,
comprising the steps of:
the radio transceiver which has not acquired its position forms a wireless network;
the radio transceivers included in the network that have acquired their positions transmit position related messages to the radio transceiver which has not acquired its position;
the radio transceiver which is acquiring its position, receives the transmitted position-related messages and acquires its position by calculation from the received position-related messages.

31. An arrangement comprising a plurality of radio transceivers including at least one movable radio transceiver wherein each of said plurality of radio transceivers is operable:
to form a wireless network with proximal ones of said plurality of transceivers and to control that network;
to calculate, when controlling a network, its position by processing position-related messages received from the proximal transceivers in the network;
to be included in a network controlled by a proximal one of said plurality of radio transceivers; and

to transmit, when included in a network controlled by said proximal controlling radio transceiver, to the proximal controlling radio transceiver at least one position-related message.

32. A radio transceiver for use in a variable arrangement comprising a plurality of radio transceivers including first order transceivers with which the transceiver can communicate directly and second-order transceivers with which the transceiver cannot communicate directly but can communicate with indirectly via a first order transceiver, arranged to determine its position by calculations which take account of where the transceiver is located because it can communicate directly with first order transceivers and which take account of where the transceiver is not located because it cannot communicate directly with the second-order transceivers.

33. A method by which a first radio transceiver that has not acquired its position can acquire its position from a plurality of radio transceivers including first order transceivers with which the transceiver can communicate directly and second-order transceivers with which the transceiver cannot communicate directly but can communicate with indirectly via a first order transceiver, comprising the steps of:

each of the first plurality of first order transceivers transmits its position;

at least one first order transceiver transmits the position of at least one second-order transceiver;

the first transceiver receives said transmitted positions and positions the first order transceiver and the at least one second order transceiver; and

the first transceiver acquires its position by calculations which take account of where the transceiver is located because it can communicate directly with positioned first order transceivers and which take account of where the transceiver is not located because it cannot communicate directly with the at least one positioned second-order transceiver.

34. A radio transceiver for use in an arrangement comprising a plurality of radio transceivers including first order transceivers with which the transceiver can communicate directly to acquire its position, arranged to

receive positions transmitted from the first order transceivers, wherein each first order transceiver transmits a position representing its location;

receive trust indications transmitted from at least one of the first order transceivers, wherein the trust indication transmitted by a first order transceiver represents the trustworthiness of the transmitting first-order transceiver; and

acquire its position by calculations which take account of the received positions and the received trust indications.

35. A method by which a first radio transceiver that has not acquired its position can acquire its position by communicating directly with a plurality of transceivers, comprising the steps of:

each of the first plurality of transceivers transmits its position;

at least one of the plurality of transceivers transmits a trust indication representing the trustworthiness of the at least one transceiver ;

the first transceiver receives the plurality of transmitted positions and the at least one transmitted trust indication; and

the first transceiver acquires its position by calculations which take account of the received plurality of positions and the at least one received trust indication.

36. A receiver for calculating its position according to a first transmitter, having a processor arranged to convolve:

(i) the probability density function representing the position of the first transmitter, sent by the first transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver.

37 A receiver as claimed in claim 36 for calculating its position according to a second transmitter, having a processor arranged to convolve:

(i) the probability density function representing the position of the second transmitter, sent by the second transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the second transmitter will be successfully received at the receiver.

38. A receiver as claimed in claim 36 or 37 wherein the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver is an approximation which simplifies processing.

39. A receiver as claimed in claim 37 or 38, wherein the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver is the same as the probability density function representing the likelihood that a transmission from the second transmitter will be successfully received at the receiver .

40. A receiver as claimed in claim 36 for calculating its position according to a plurality of transmitters, having a processor arranged to calculate a probability density function for each of said plurality of transmitters by the convolution of

(i) the probability density function representing the position of one of the plurality of said transmitters, sent by said one transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from said one transmitting receiver will be successfully received at the receiver

and arranged to combine the resultant plurality of probability density functions.

41. A receiver as claimed in claim 40 wherein the combination of the resultant probability density functions involves pair-wise combination of probability density functions.

42. A receiver as claimed in claim 41 wherein the pair-wise combination involves the multiplication of one probability density function with another.

43. A receiver as claimed in claim 40 wherein the pair-wise combination involves the addition of one probability density function with another.

44.A receiver as claimed in claim 42 or 43, wherein the combination is a weighted combination.

45. A receiver as claimed in claim 44 wherein the weighted combination increases the contribution made from probability density functions derived from trusted transmitters.

46. A method of calculating the position of a receiver by communication with a plurality of transmitters comprising the steps of, for each of said plurality of transmitters,

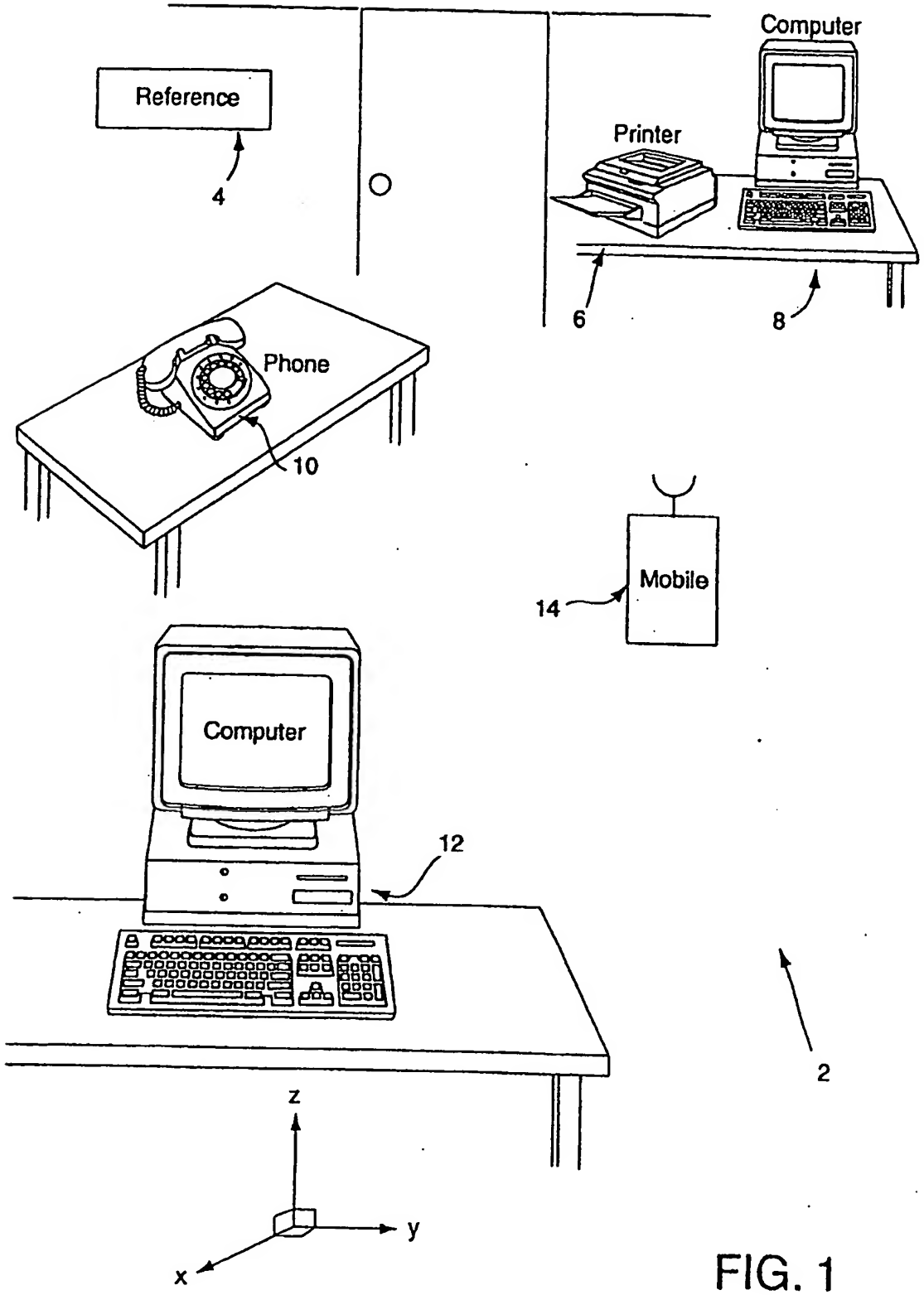
convolving:

(i) the probability density function representing the position of a transmitter, sent by the transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the transmitter will be successfully received at the receiver

and combining the plurality of convolution products.

47. A method as claimed in claim 48 wherein the receiver is the Master transceiver in an ad-hoc network of Bluetooth transceivers and the plurality of transmitters are Slave transceivers in that Bluetooth network.


Reference
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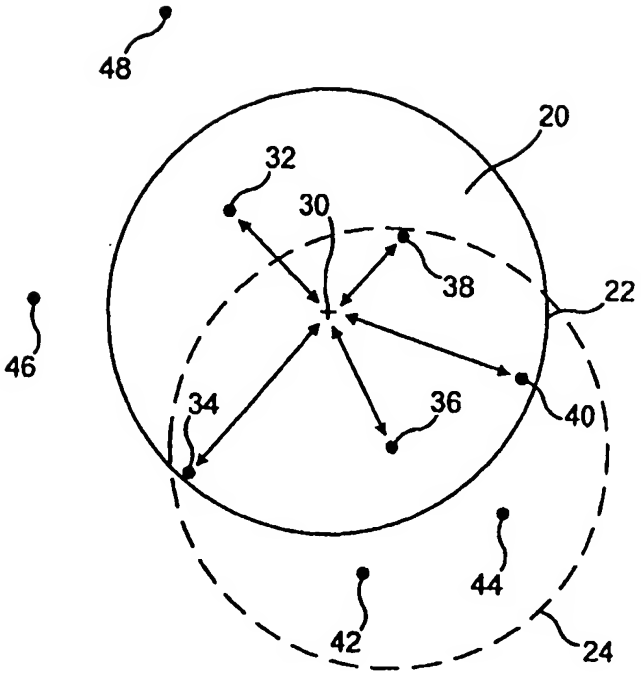
Computer
Printer
6
8
Phone
10
Mobile
14
Computer
12
2
z
y
x

FIG. 1


48
20
32
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38
22
46
34
36
40
44
42
24

FIG.2

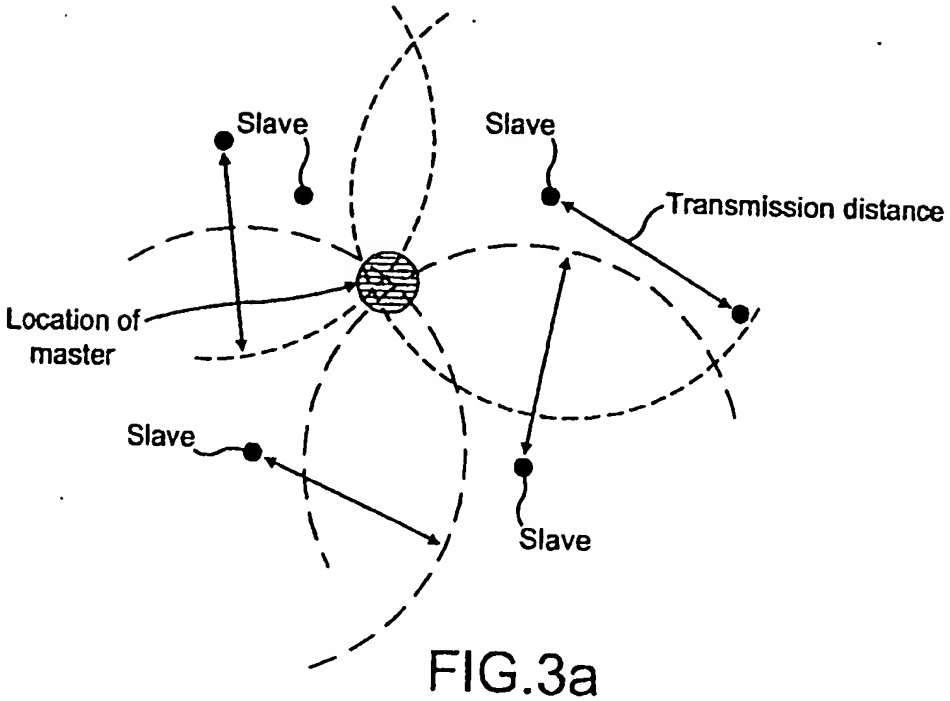
Slave
Slave
Transmission distance
Location of master
Slave
Slave

FIG.3a

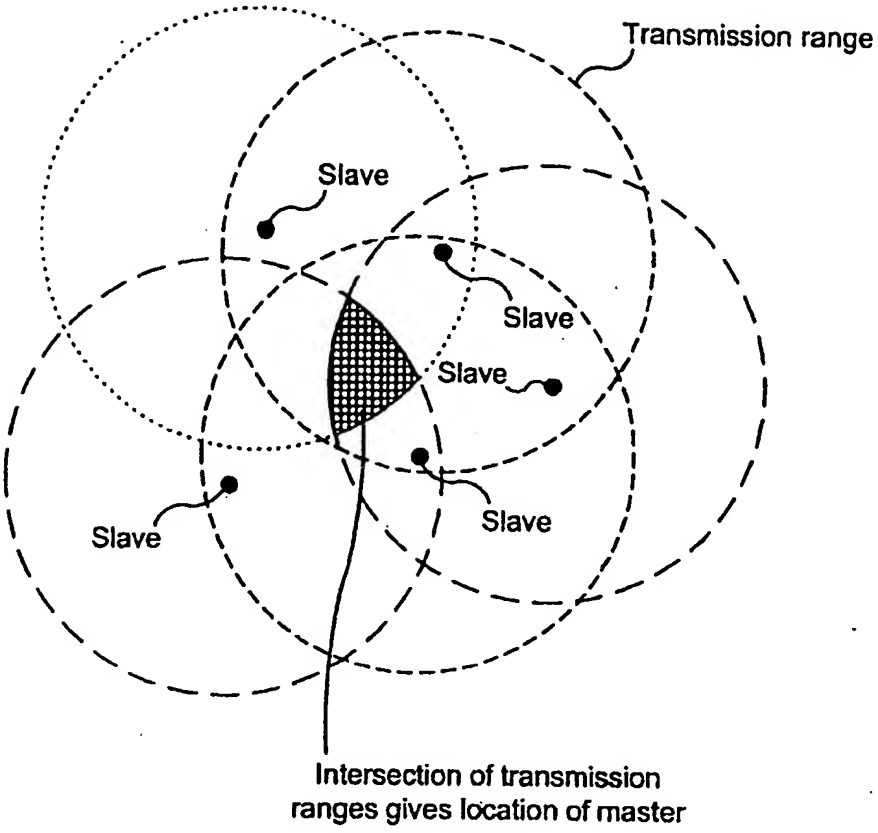
Transmission range
Slave
Slave
Slave
Slave
Slave
Slave
Intersection of transmission ranges gives location of master

FIG.3b

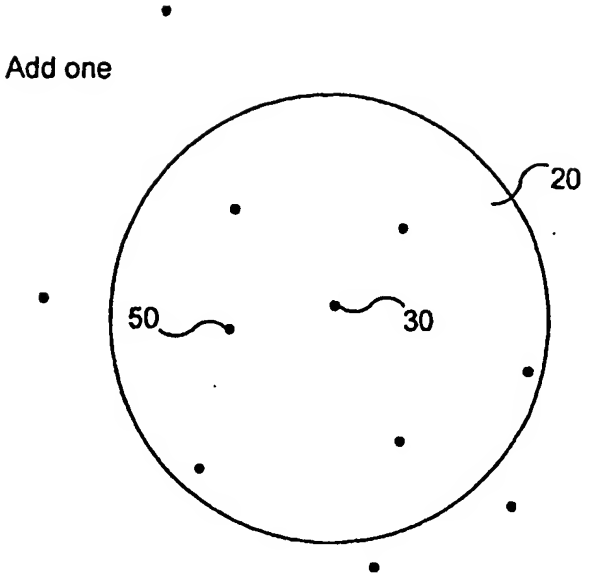

FIG.4a

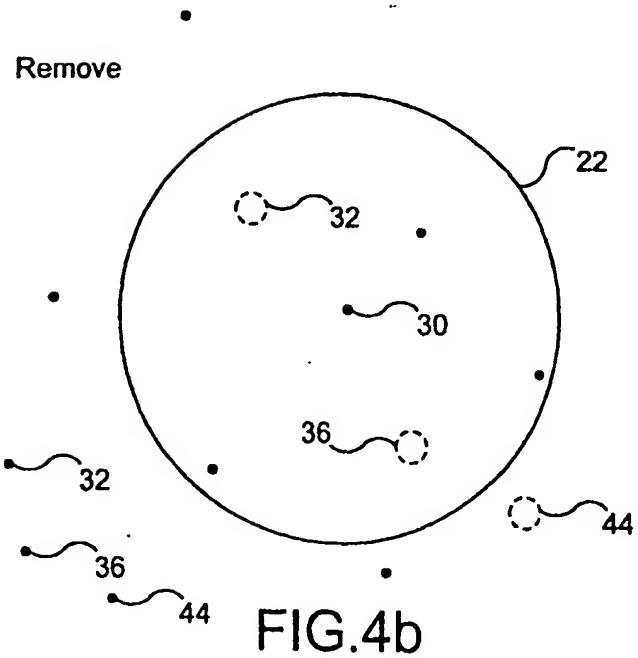

FIG.4b

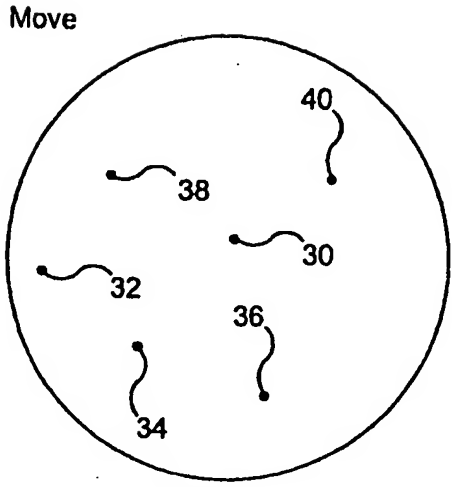

FIG.4c

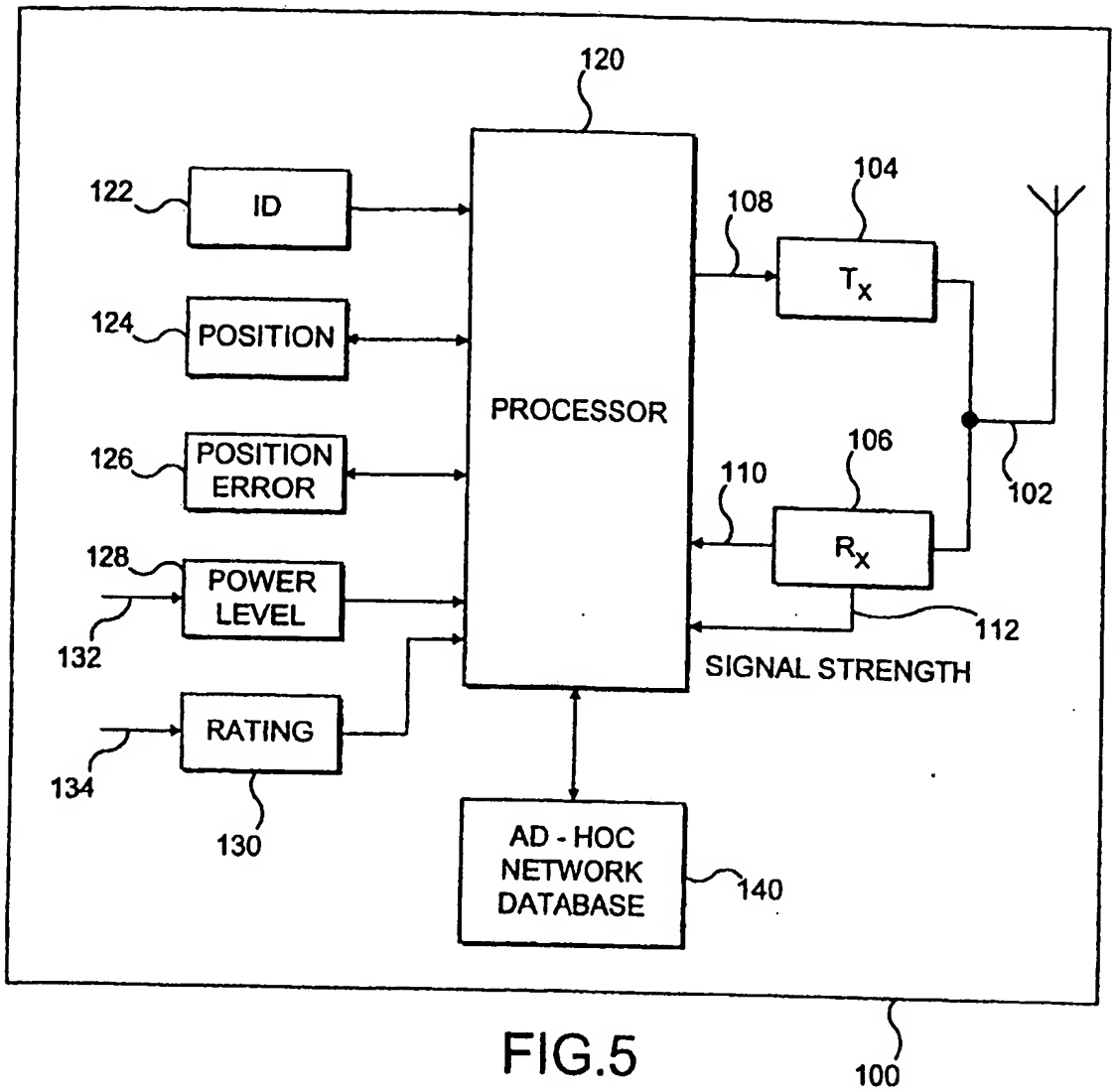
120
122
ID
124
POSITION
126
POSITION ERROR
128
POWER LEVEL
132
RATING
134
130
PROCESSOR
108
104
T_X
106
110
R_X
102
112
SIGNAL STRENGTH
AD - HOC NETWORK DATABASE
140
100

FIG.5

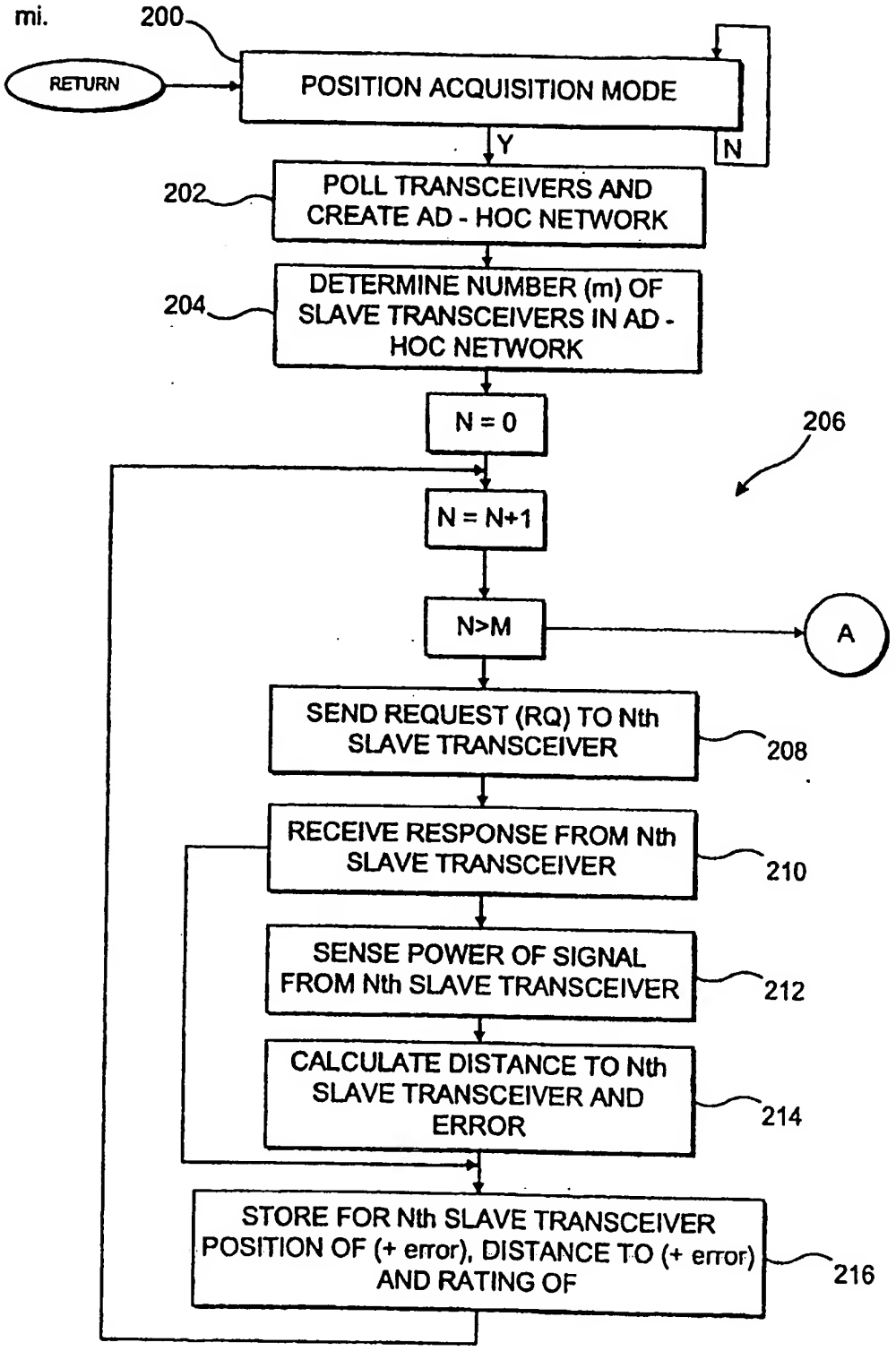
mi.
200
RETURN
POSITION ACQUISITION MODE
Y
N
202
POLL TRANSCEIVERS AND CREATE AD - HOC NETWORK
204
DETERMINE NUMBER (m) OF SLAVE TRANSCEIVERS IN AD - HOC NETWORK
N = 0
206
N = N+1
N>M
A
SEND REQUEST (RQ) TO Nth SLAVE TRANSCEIVER
208
RECEIVE RESPONSE FROM Nth SLAVE TRANSCEIVER
210
SENSE POWER OF SIGNAL FROM Nth SLAVE TRANSCEIVER
212
CALCULATE DISTANCE TO Nth SLAVE TRANSCEIVER AND ERROR
214
STORE FOR Nth SLAVE TRANSCEIVER POSITION OF (+ error), DISTANCE TO (+ error) AND RATING OF
216

FIG.6a

m2.
POSITION CALCULATION

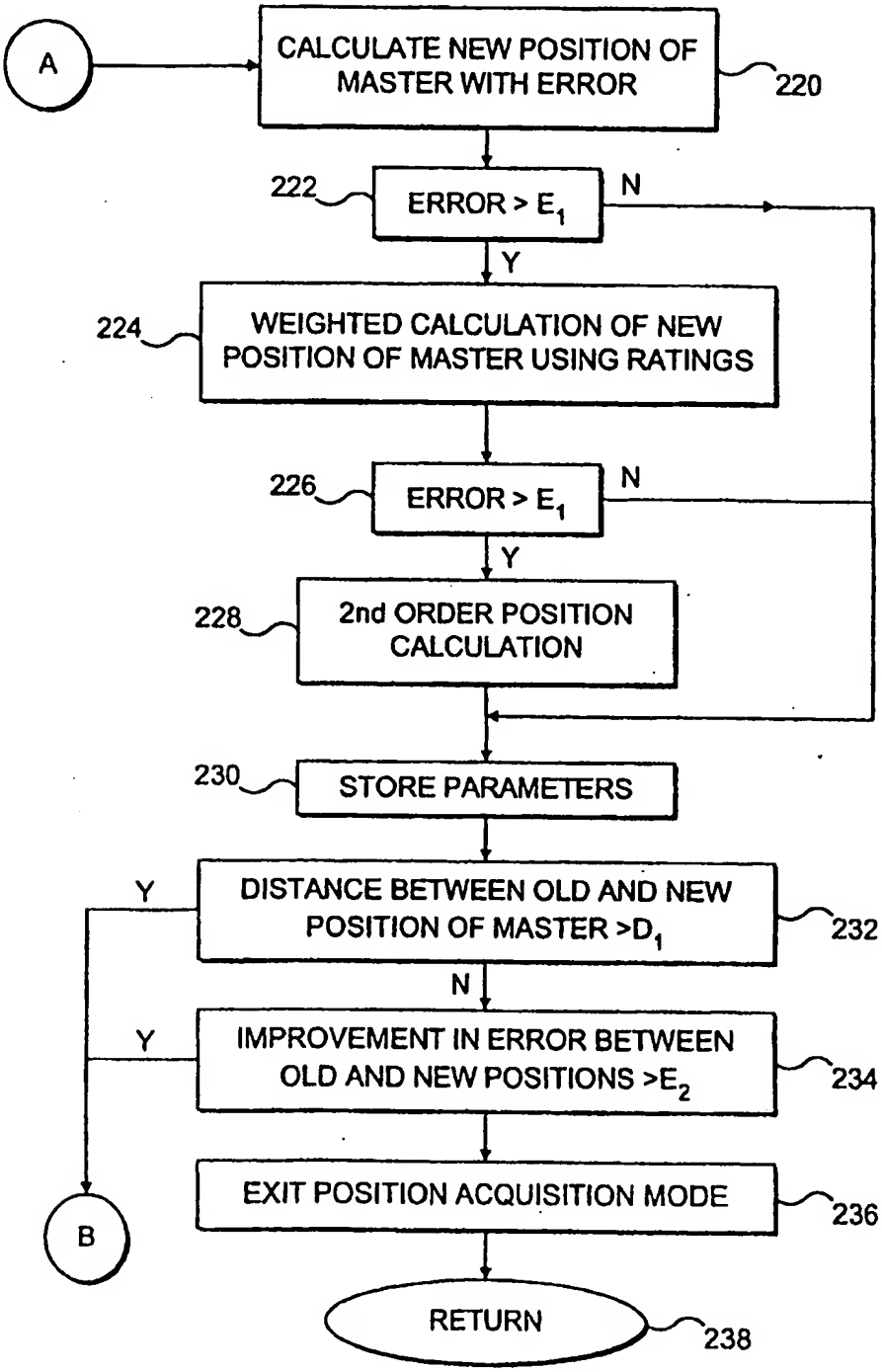

FIG.6b

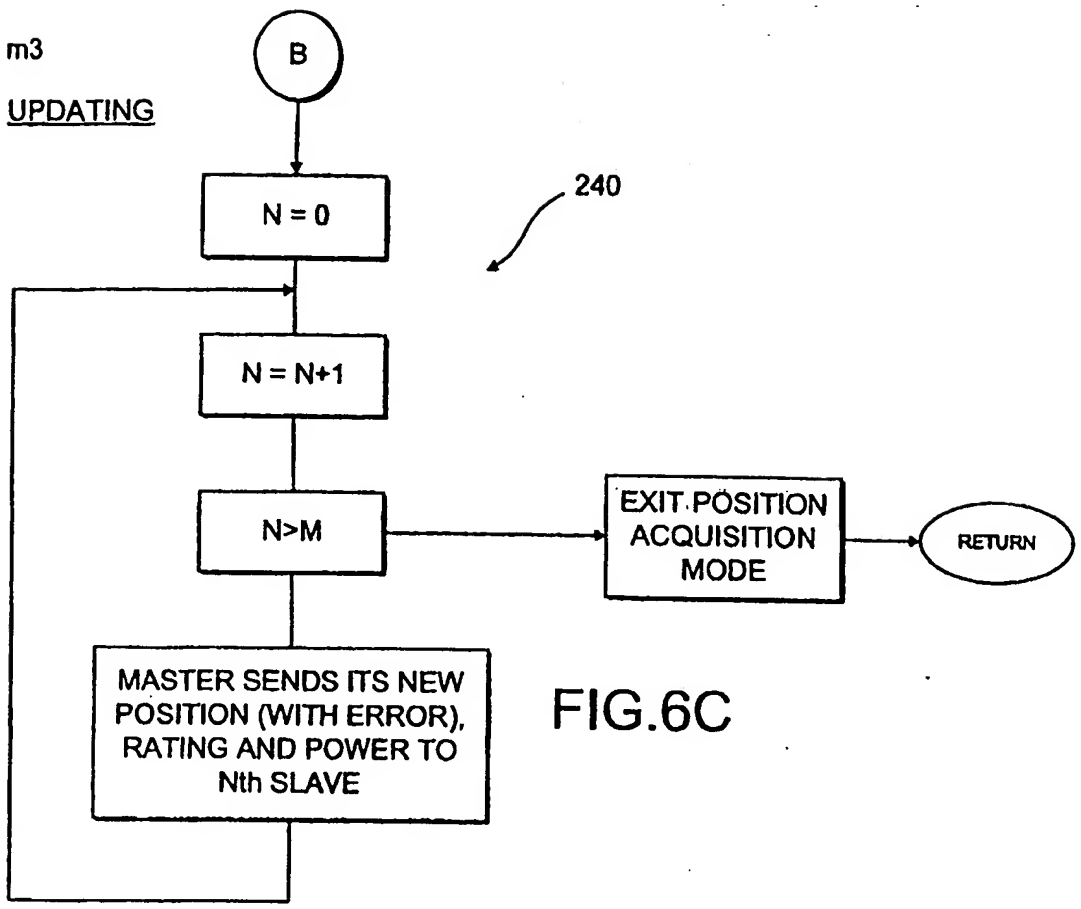
m3
UPDATING
B
N = 0
240
N = N+1
N>M
EXIT POSITION ACQUISITION MODE
RETURN
MASTER SENDS ITS NEW POSITION (WITH ERROR), RATING AND POWER TO Nth SLAVE

FIG.6C

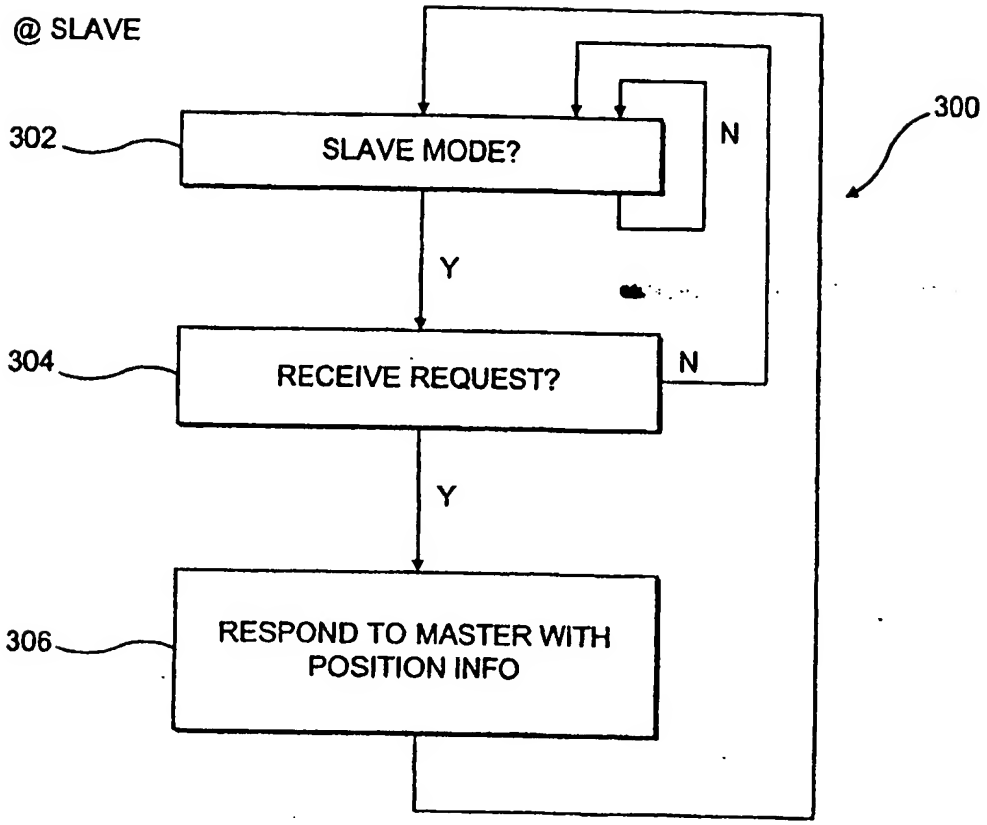
@ SLAVE
302
SLAVE MODE?
N
300
Y
304
RECEIVE REQUEST?
N
Y
306
RESPOND TO MASTER WITH POSITION INFO

FIG.7a

@ SLAVE

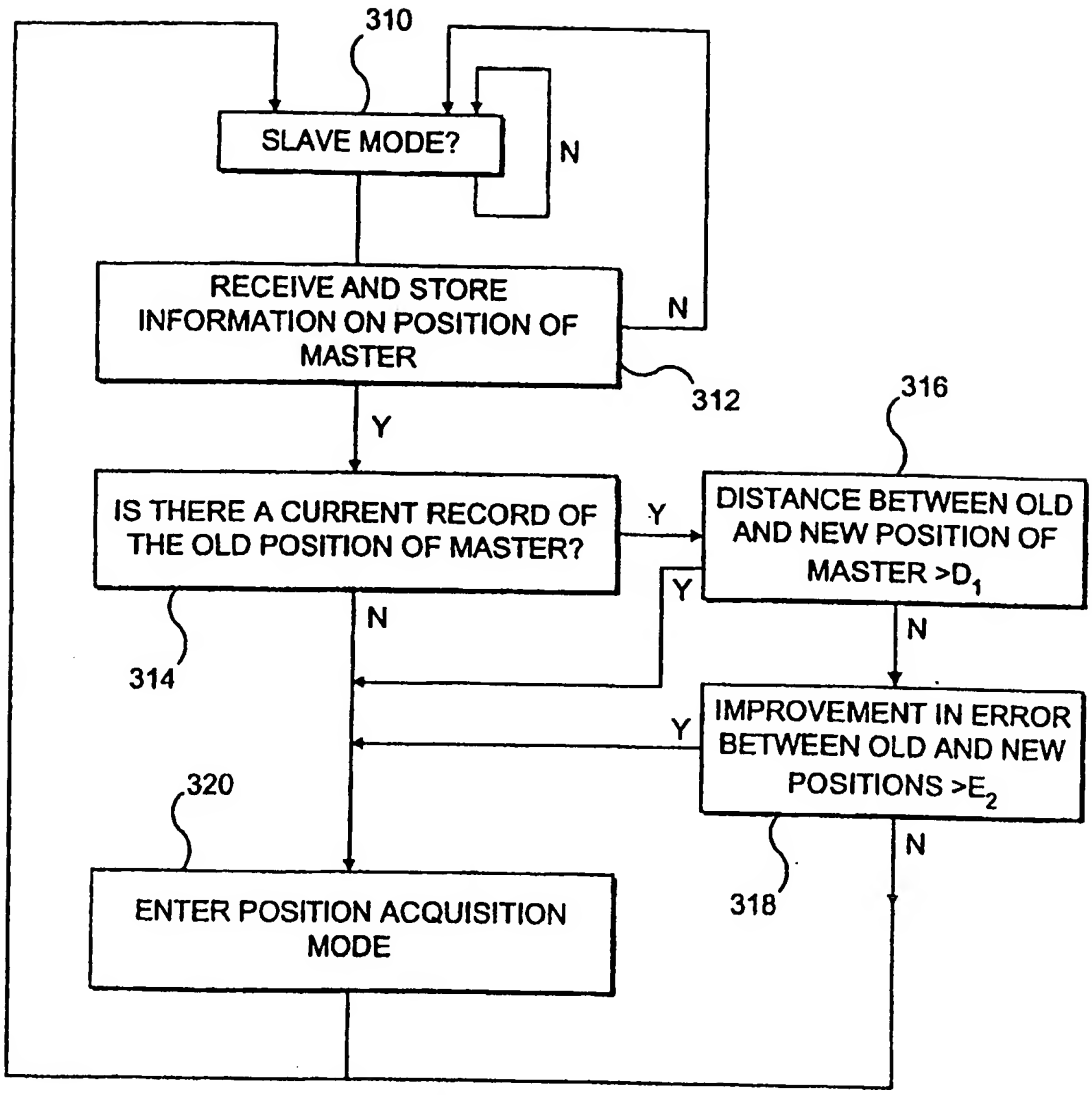
310
SLAVE MODE?
N
RECEIVE AND STORE INFORMATION ON POSITION OF MASTER
N
312
Y
316
IS THERE A CURRENT RECORD OF THE OLD POSITION OF MASTER?
Y
DISTANCE BETWEEN OLD AND NEW POSITION OF MASTER >D_1
Y
N
314
N
IMPROVEMENT IN ERROR BETWEEN OLD AND NEW POSITIONS >E_2
Y
320
N
318
ENTER POSITION ACQUISITION MODE

FIG.7b

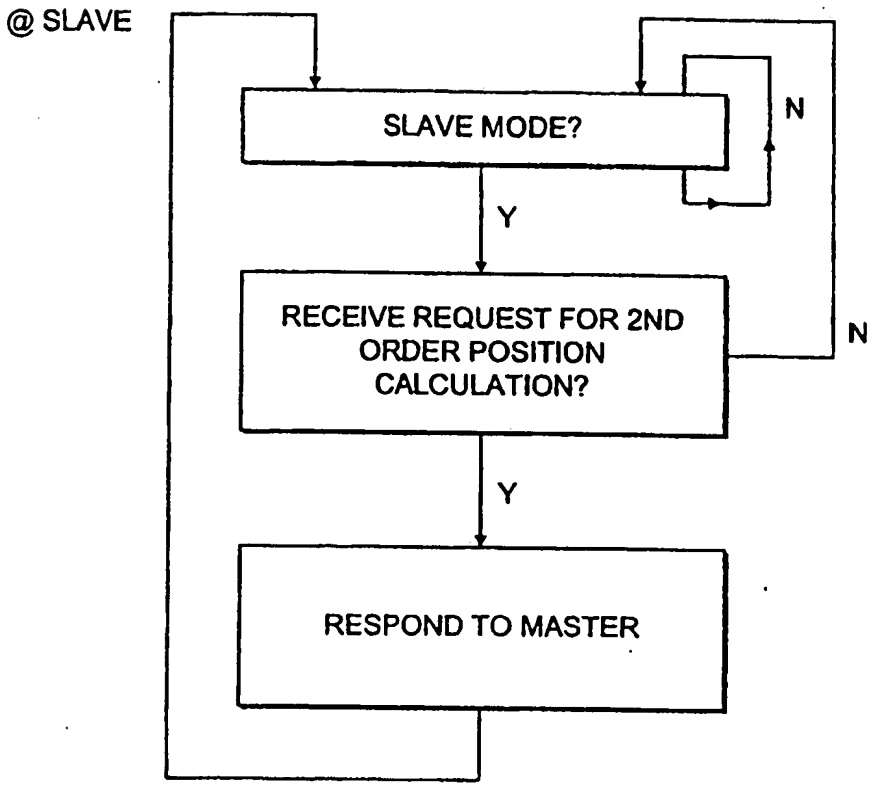
@ SLAVE
SLAVE MODE?
N
Y
RECEIVE REQUEST FOR 2ND ORDER POSITION CALCULATION?
N
Y
RESPOND TO MASTER

FIG.7c

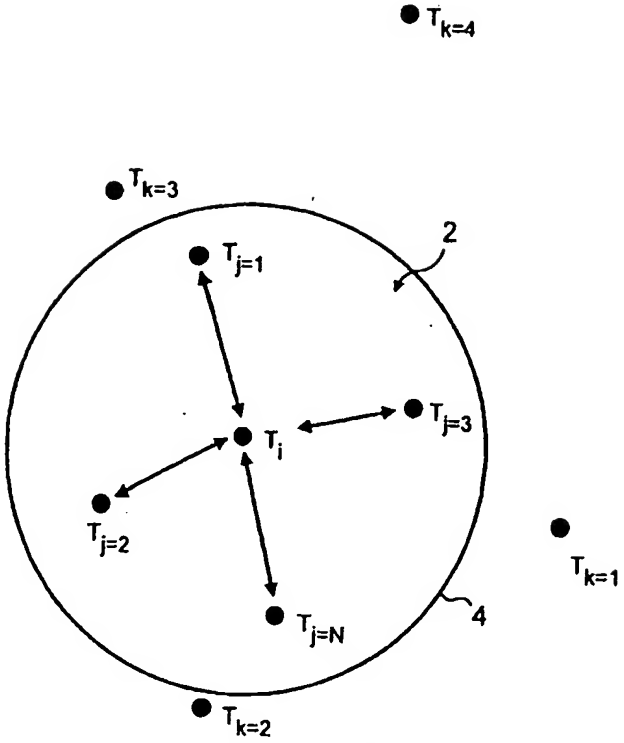

FIG. 8

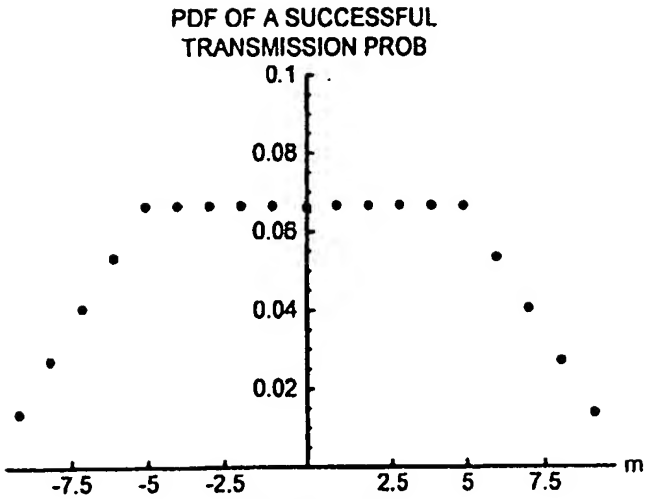
PDF OF A SUCCESSFUL
TRANSMISSION PROB
0.1
0.08
0.06
0.04
0.02
-7.5
-5
-2.5
2.5
5
7.5
m

FIG. 9

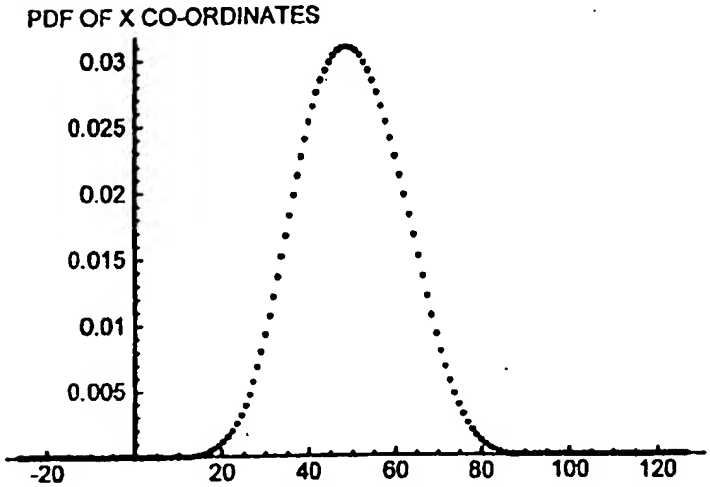
PDF OF X CO-ORDINATES
0.03
0.025
0.02
0.015
0.01
0.005
-20
20
40
60
80
100
120

FIG. 10

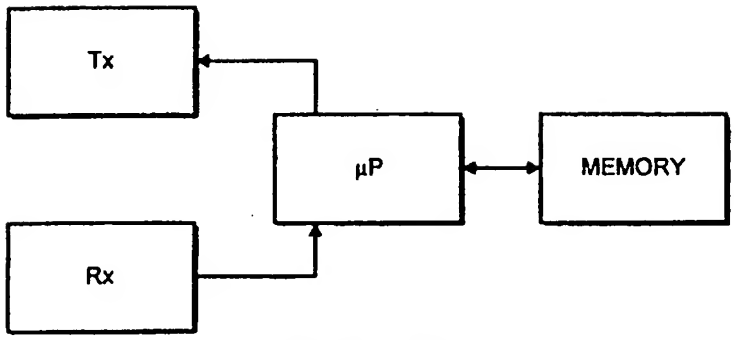

FIG. 11